KOTO

ON THE GEOLOGIC STRUCTURE OF THE MALAYAN ARCHIPELAGO

東京帝國大學紀要

理科

第十壹冊第貳號

THE

JOURNAL

OF THE

COLLEGE OF SCIENCE,

IMPERIAL UNIVERSITY OF TŌKYŌ,

JAPAN.

VOL. XI., PART II.

東京帝國大學印行

PUBLISHED BY THE UNIVERSITY.

TŌKYŌ, JAPAN.

1899.

MEIJI XXXII.

Publishing Committee.

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On the Geologic Structure of the Malayan Archipelago.

By

B. Kotô, *Ph. D. Rigakuhakushi,*
Professor of Geology, Science College, Imperial University, Tôkyô.

With Plate I.

In the following pages, I propose to give a brief sketch of the geologic and tectonic structure of the island-world of South-eastern Asia, usually comprehended under the name of the Malayan Archipelago. The motive of my taking up the present subject was to enable me to compare the physical features of the island of Taiwan with those of the Far Eastern Indies, there being much in common between them. My notes have now so far accrued as to make me hope that some service will be done by their publication in a connected form. The great Viennese geologist, Prof. E. Suess, has already drawn a lively picture of the structure of these islands, in his 'Das Antlitz der Erde,' and this I have made the foundation of my paper; but as the Malayan Archipelago fills only a small section of his work, and has besides become much better known than it was when he wrote about it, I have found it necessary both to enlarge and to modify his account.

I. Outer Eastern Archipelago.

The Tangla Mountains, in the very heart of the 'Roof of the world', lying between the Himalayan and the Kuen-lun system, run from W. N. W. to E. S. E. From the region of mountain-virgation in the East Tibetan frontier, the Tangla proceed in a south-easterly direction towards the 'peripheric' region, and then, turning to the south, divide up into the parallel chains in Indo-China and Burma, which constitute what is now known as the Further India mountain-system of v. Richthofen.

The westernmost or Arrakan chain, the youngest of the system, is built up of non-fossiliferous sandstones and shales, usually referred to as Cretaceous,[1] accompanied by serpentine, petroleum wells, salt springs and mud-lumps. It, therefore, resembles very closely the Carpathian ranges, the Caucasus, and some parts of the Apennines in many geological features. It has the Flysch facies. Now, this chain (*yoma*) forms the starting point of the *Malayan arc* which goes through the small islands of Cheduba and Reguain, the Preparis and the Cocos to the Andamans and the Nicobars, and then proceeds to Babi (Simalur), the Miocene coal-bearing Nias, and the Mentawei Islands (volcanic according to Maass) as far as Engano. Along this line of elevations, those of *Nicobar Group*, especially Kar Nicobar, have become, geologically speaking, comparatively well known, through the labours of Hochstetter and C. Schwager.[2] The geologic components of the Nicobars may be arranged in three

1) Theobald, Geol. Surv. India, 1873. Lately, Noetling has revised the division of the Tertiary system of Burma, and the Axial ridge of the Arrakan-yoma now under consideration, and thinks that they belong to the Cretaceo-Eocene formation. *Vide* Records Geol. Surv. India, Vol. XXVIII, p. 59.

2) 'Reise der Novara', Bd. II, p. 83 *et seq.*

groups, viz., (1) plutonic rocks of the gabbro and serpentine class with hornstone veins, intruding into (2) a complex of micaceous, compact sandstone, shale, marl, and plastic clay, the whole being overlaid by (3) raised coral-reefs. The sandstone banks bear impressions of a Fucoid, *Chondrites nicobarensis*, Hochst. on the plane of sedimentation, like the rock at Biô-kô-sha* on the east coast of Taiwan. The plastic clay abounds in Foraminifers, which belong to the Young Miocene. Geologically important forms among them are *Quinqueloculina*, *Bulimina*, *Lagena*, *Nodosaria*, *Cristellaria*, *Sphæroidina*, *Globigerina*, and *Orbulina*.

To the east of the first chain there lies another, which begins near Bahmo in the Yünnan frontier, and extends southwards between the Irrawaddi and Sitoung rivers, the relief becoming lower in the Pegu region, until it becomes merged in the sea between the Andaman group and the Malayan peninsula, which is regarded as its continuation. The upland of Pegu is of Miocene age (the Pegu division); the loose sandstones and clay, of which it is built up, contain many small shark's teeth besides a large *Charcharias* (*Prionodon* sp.), some two inches long, together with *Daphoderma caelata*, Reeve, *Pecten* cf. *favrei* d'Arch. and Haime, and *Cardium* sp. Squaline remains occur particularly in the upper Miocene and in the basal member of the Pliocene (the Irrawaddi division)[3] also.

The region lying east of the Sitoung river seems to be mainly Palæozoic, and certainly proved to be in part Carboniferous. Granites, old-looking sandstones and slates, so says Sievers,[4] extend down to Singapore, and thence to Banka, Billiton,

* The village Biô-kô-sha = 猫公社.

3) Noetling, *loc. cit.* p. 63.

4) 'Asien.'

and finally Borneo, unless, according to the recent researches of Verbeek and Fennema, Karimon Java should be taken to be the true prolongation of the Billiton line.[5]

The Pegu region and the adjoining countries are not free from traces of volcanic activity. In the neighbourhood of Pegan, the basaltic volcano of Puppa-doung, 500 feet high, raises its head from the surrounding Tertiary formation, as well as a trachytic hill near the mouth of the Bassein river. Connection of these with the volcanoes of Sumatra can be traced through Narcondam and Barren Islands.

Sumatra.

Sumatra, the southern continuation of Pegu and the Malayan peninsula, shows, according to Suess,[6] intrusive granite, schists, Carboniferous* and Tertiary beds with greenstones, all thrown into manifold long ridges producing steep cliffs on the south side, and in the north flattening out into a nearly impenetrable but partly inhabited swampy land. Two parallel chains of volcanoes run along the axis of the mountain folds, one of them near the southern steep coast, whose ejected matter is Miocene andesite, the other lying far in the interior and constituting a chain of modern volcanoes. Many transverse fissures cross the latter chain, along which the seats of active vent are shifting to and fro, as in the Andean cordillera. About nineteen volcanoes can be counted, of which seven belong to the active kind, Gunung Korintji and G. Dempo being lofty summits among them.

5) 'Description Géologique de Java et Madoura.'

6) 'Das Antlitz der Erde.'

* Upper Carboniferous Limestone with *Fusulina*, in Padang on the west coast.

We next come to the Sunda Strait, where the island of Krakatoa made a sudden explosion in 1883.

Java.[7]

Although the large island of Java formed a part of Sumatra at the end of the Miocene period, it differs from its western neighbour in being built up mainly of the Young Tertiary. Palæozoic and still older complexes are only found in the island of Karimon Java, off the northern coast, while Cretaceous and Eocene beds occur in insular patches within the Tertiary upland that constitutes the central axis of the island; the south coast consists mainly of Younger Miocene rocks, while the north is an alluvial plain. Petroleum-wells are located mainly on the line between Samarang and Rembang on the north coast in Miocene beds.

Java owes its special topographic relief not to the sedimentary but to volcanic formations. The enormous masses of extravasation and the vents of volcanic activity are arranged linearly and correspond to the longest extension and the central axis of the island. East Java possesses a double series of longitudinal fissures in its crust crowned with mighty cones, one among them being the active volcano, Semeru, which is the highest elevation in the whole island, being 3,676 metres above sea-level. The two chains converge at the narrow, middle portion of the island with the extinct Penususpan and Slamat at their junction. Their conjoined, and single fissure extends through occidental Java to the well-known Krakatoa, and thence to Sumatra, traversing by the way three volcanic districts, where

7) Verbeek et Fennema, 'Description Géologique de Java et Madoura,' 1896.

minor fissures or lines of dislocation are oriented parallel and also obliquely to the main line. The Strait of Sunda on the west and that of Bali on the east are also transverse fractures which separate the opposite islands by narrow channels.

There are altogether 131 volcanoes, of which we may mention the following six active ones; Raun, Lemongan, Kelut, Merapi in Solo, Guntur, and Gede, besides Semeru already noticed. The explosion of Papandayang (?Gelungung) in West Java in 1822 is celebrated for having destroyed forty villages and left a large lake in their place.

It is to be remarked in connection with the Javanese volcanoes, that the leucite rocks, so rare in Asia, occur in the island of Bawean, and in G. Ringgit in East Java.

The Small Banda Group.

The volcanic chain, hitherto traced, reaches its end in Pantar, and the zoological boundary established by Wallace[8] between Bali and Lombok seems to have no geological significance, as is also the case of non-coincidence between the geological and zoological limits in the West Indies. Lombok's neighbour is Sumbawa, in which is located the vent of Tembora, the only match for Papandayang in Java, and well known since its destructive explosion in 1815, which darkened the sky over 3,000 miles. Floris[9] is volcanic, and its rocks are andesite and basalt. The sedimentaries are tuffs and conglomerate derived from the effusive rocks, and cemented by lime; the conglomerate gradually passes upwards to the coral-reef limestone, the age of which is,

8) Journal Royal Geogr. Soc. 1863, p. 231.

9) Wichmann, 'Bericht über eine Reise nach dem Indischen Archipel.' *Tijdschr. v. h. Kon. Nederl. Aardrijksk. Gen.*, 1891, p. 92.

according to K. Martin,[10] post-Pliocene. A tectonic line, running S. W.—N. E. at the east end of the island, carries three volcanoes, viz., the smoking Parampuwan, Leworoh which exploded in 1881, and Ilimandiri, besides Gunung Api (G. Ija), which is in the solfataric stage.

Andonara is geologically speaking the exact repetition of its western neighbour. Here we have the East Indian Stromboli, called by the name of Pulu Komba. The reef-limestone of the island is now considered by K. Martin[11] to be Quaternary, though its age was fixed formerly as that of the Young Miocene,[12] supported by the occurrence in it of *Clementia papyracea*, Gray, *Cœlaria singularis* Mart. and *Hydonophora astræoides*, Mart., but as the first of these still survives in the neighbouring seas, its value as the leading fossil of the Miocene must be of doubtful character. It should be remarked by the way that the same fossil bivalve, from an unknown locality in Japan, is said to be in the Museum at Leiden, brought there by v. Siebold. Lately, occurrences of *Clementia* have been reported from several localities in the Neocene of Japan, and one species is still living near the entrance of the Bay of Tokyo. A footnote on page 136 in Wichmann's paper[13] has given rise to much bitter discussion between Martin and Wichmann in the '*Neues Jahrbuch für Mineralogie*,' etc., 1891–92. The latter[14] taking into consideration the special stratigraphy of these coral limestones and their very elevated position as raised reefs, entertains the view that the coral-limestones, distributed as raised terraces nearly through-

10) *Op. cit.* (9), VII, 1890, p. 265.
11) *Loc. cit.*
12) 'Tertiärschichten auf Java.' p. 36.
13) *Loc. cit.* (9).
14) *Tijdschr. v. h. Kon. Nederl. Aardrijksk. Gen.*, *Jaargang*, 1892, p. 243.

out the East Indies, belong to the Neogene Tertiary. At many localities, he says, the porous limestone is *covered with* marls of the character of lagoon deposits, and containing Foraminifers such as have been studied by the late C. Schwager[15] in the marls from Kar Nicobar, and in the marls from Luzon by F. Karrer.[16] Both writers class the respective bed as belonging to the Young Tertiary.

It may here be pointed out that A. Agassiz[17] also mentions raised coral-reefs which form terraces of considerable height in the Viti group, as in nearly all other islands of the South Pacific, and he repeatedly speaks of the Neocene age of these limestones but only in order to discriminate them from modern reefs which have not thickness enough to give any support to the Darwin-Dana's depression theory of coral islands.

The discussions about the age of these coral-reef limestones possess special interest for us, because the same formation recurs in great extent in Taiwan and the Riukiu islands, and the study of these organogenic rocks in Japan has scarcely yet begun.

With Lomblen and Panter we come to the end of the great Malayan arc., and now enter into a difficult but very interesting part of our theme. It is generally asserted that the 'girdle of fire' in the west Pacific starts from the Aleutian Islands and Kamtschatka through Japan and the Philippines to the great arc of the Malay Archipelago, and that a line branches off from the volcano, Dampier,[18] at the western extremity of New Guinea, to the Bismarck Archipelago and the Solomons up to New Zealand,

15) 'Reise der Fregatte Novara', Geologischer Theil, Bd. II, p. 187 et seq.
16) v. Drasche, 'Fragmente zu einer Geologie der Insel Luzon', p. 79.
17) Amer. Jour. Sci., February number, 1898.
18) Naumann, 'Geognosie', I, 1858, p. 92.

forming what is comprehended under the name of the Australian volcanic chain. L. v. Buch years ago pointed out that the long band of Asiatic volcanoes marks off the natural boundary of the Asiatic continent, and this view seems more natural than that of the Bali-Lombok line of Wallace,[19] based on the peculiar distribution of the higher animals. Wallace himself particularly calls attention to the fact that his division of the Archipelago into two regions, characterised by a striking diversity in the natural productions of the islands does not correspond to any of the physical divisions of their surface. The volcanic chain runs through both regions, and geologically they are inseparable.

Looking more into the details of the special position of the Banda volcanoes, which is our immediate subject, we are confronted with difficulties in tracing out the tectonic lines of the region, and the views of geologists are by no means in accord. C. Naumann[20] declines to admit the existence of an independent chain here, but sees in the volcanic island of Nila the intersecting point of his middle system, that is, of his Formosa-Nila band with the Sunda chain. Junghuhn,[21] on the contrary, imagines the Banda series to be a prolongation of Timor, which when he wrote was supposed to be volcanic.

According to Wichmann,[22] the great volcanic band of the Sunda Islands terminates in Panter, since the easterly islands, inclusive of Wetter, carry no volcanic cones, Wetter being for the greater part built up of Palæozoic and Mesozoic beds. With Roma begins a new system, followed by Dammer, Tiow, Nila,

19) Journal Royal Geogr. Soc., 1863, p. 231.

20) *Loc. cit.* (18).

21) 'Java' Bd. II, Leipzig, p. 834.

22) 'Gesteine von der Insel Kisser', *Beiträge zur Geologie von Ostasien*, Bd. II, Leiden, 1887, p. 197.

Serua, Namuk, and the Banda Islands, collectively called the South-west Islands, whose arrangement is curviform, with the inner side towards the north-west. All are entirely volcanic. An active volcano of Riadur crowns Roma; Dammer has the active Wuarlili and a few solfataras; there are volcanoes and solfataras also in Nila; Tiouw has its record of eruption in 1660 and 1693. Upon Serua are three volcanoes, one of which made destructive explosions in 1683, 1694, 1844, and 1862?, while Pulu Manuk (Bird island) has a crater and large deposits of sulphur. In a north-westerly direction we have the Banda Islands, one member of which is Gunung Api (burning mountain) which was in eruption in 1820; and with this apparently ends the Banda chain. We shall come again to it later on.

A glance at the map will suffice to convince us that the geological position of Timor and its neighbouring islands between the Banda and Sunda chains is a peculiar one. Of Sumba or Sandal-wood island there is nothing known from the geological point of view, except that its interior is table-shaped, fringed by raised coral-reefs which are overlaid by marls; but Timor is the classical ground of geology in the whole East Indian Archipelago. Near the boundary between the Dutch and Portuguese possessions, which divides the island into nearly east and west halves, several formations[23] appear to be fairly represented, which, counting upwards, are as follows:—(1) the Archæan amphibolite, (2) the Permian and (3) Trias, and finally reef-limestones. At Baung, not far from the well-known Kupang, the reef-limestones cap the Eocene Nummulitic limestone with *Alveolina*;[24] in other places

23) Wichmann, *Tijdschr. v. h. Kon. Nederl. Aardrijksk. Gen.*, *Jaargang* 1892, p. 255.
24) K. Martin, *ibid.* 1890, p. 269, and Verbeek, *ibid.* 1891, p. 15.

granite, gabbro, serpentine, melaphyre-like rocks, spherulitic quartz-porphyry, and Tertiary effusives make their appearance. The Archæan is widespread in the Portuguese domain, accompanied by mica-schist and phyllite; and it seems highly probable that the complex of crystalline schists extends through the islands of Kisser, Letti, and Babbar as far as Buru, thus constituting the second or outer arc of the Banda chain.

At Ajer Mati, south of Kupang, already referred to, a red Crinoidal limestone crops out at many points, which caused the late Beyrich[25] and K. Martin[26] to write monographs, to the effect that this limestone belongs to the Carboniferous. Lately Rothpletz[27] has worked over the collection made by Wichmann, and has come to the conclusion that here we have the Permian or Permo-carboniferous but not the Carboniferous. The collection represents a rich fauna, together with Ammonites (*Arcestes megaphyllus, A. tridens*), resembling in many respects those of Salt-Range, Armenia, and Texas. It is to be remarked that none of the exclusively Permian species of Timor occurs in Australia or America. Wichmann made a happy find near Baä in Rotti, lying off the south-west coast of Timor, where a limestone abounds in bivalves upon the plane of sedimentation. These together with other fossils, were also entrusted to Rothpletz for examination, who found many species of *Halobia*, *Monotis*, and *Daonella*. Just as the Permian fauna did not show any close relation to the eastern (Pacific) fauna, so also there are no relations between the East Indian Triassic fauna and that of New Caledonia, New Zealand, and Japan, where the *Monotis*

25) *Abhdlg. d. K. Akademie d. W.*, 1864, Berlin.
26) *Beiträge zur Geologie Ostasiens u. Australiens*, I. p. 15.
27) *The American Naturalist;* 1891, p. 959. Vide also *Palæontographica*, Bd. XXXIX, p. 59.

seems to be represented by the genus *Pseudomontis*. The Liassic and Oolitic fossils of Rotti are represented by *Arietites geometricus*, *Harpoceras* cf. *eseri*, and *Belemnites gerardii*. Sawu is geologically like Rotti. I know nothing about the literature concerning the geology of Ombaai.

The islands Sumba, Timor, Ombaai, and Wetter are remarkably free from volcanoes, though situated amidst the chains of extravasation of subterranean magma. They intervene between the belts of Banda and Sunda, from which we might without hesitation conclude that the two constitute independent series. On this account, Timor is sometimes looked upon geologically as one of the South-west Islands, at other times as a prolongation of the South-east Islands, of the Banda group. After all, Timor and Sumba have not yet got, geologically speaking, their position as true members of the Malayan Archipelago, and they are sometimes even spoken of in connection with Australia.

Be that as it may, the Banda chain of volcanoes, already referred to, is circumscribed exteriorly by the similarly bending series of the South-east Islands which begins either from Kisser or Letti. We will now follow it.

Kisser seems to be a mere cliff of crystalline schists, surrounded by Tertiary and Recent coral-reefs, while Letti consists of rolling hills of Miocene sandstone and marl, with an east-west strike, underlaid by old schists. Moa is a little larger, and geologically somewhat exceptional. A lofty peak like Teneriffa stands on the east coast and is believed to be an extinct volcano, while the low-lying tract consists essentially of coral limestones. As the next island in the series comes Lakor, which is a mere coral limestone. Luang consists of marls and sandstones (Tertiary?), fringed with coral islands; the same should be the case

with Sermatta. Tertiary sandstones with a nucleus probably of crystalline schists make up the island of Babber.* The majority of the Tennimber group belong to the Tertiary and Recent coral formations; and a crystalline limestone and quartzite have been reported to occur in Seera, one of the above group. In the Kei Islands, K. Martin mentions an occurrence of the Eocene limestone with *Alveolina*; Koor resembles it in its geology. Watu-Bella Island seems to be built up of crystalline schists (amphibolites and quartzites), while Tjoor forms an exception, being a volcanic island, an eruption in which in 1559, caused a great damage to the plantations. Ceram-Laut, Suruaki, Goram, and Manawoka consist of crystalline schists, while the minor islands among them are of Recent coral formation. Manawoka may possess an extinct volcano, but this is not quite certain. Ceram (Serang) has, according to K. Martin,[28] an equatorial mountain, at least in the western half, is cliffy in the north, and in the south is composed of hills of crystalline schists with Alluvial plains around coves. High mountain limestone (the Buru limestone of Martin), and another complex of limestone, either Quaternary or Tertiary, seem to have a wide distribution, especially in the Buano island. Neovolcanic rocks are scarce, except in the south point of Huamaul or Small Ceram. Wichmann[29] cites the occurrence of granite, syenite, quartz-porphyry and mica-porphyrite. The northern half of the sister island Buru[30] appears to be mountainous, and made up of crystalline schists. Sandstone, overlaid by a Mesozoic (Jurassic) limestone with *Aptychus* and

* An occurrence of the Jurassic limestone is noticed by Suess, in his 'Das Antlitz der Erde', Bd. II, p. 208.

28) *Verhandl. d. Gesell. f. Erdkunde z. Berlin*, Bd. 21, S. 513.

29) 'Beiträge zur Geologie von Ostasiens etc.', Bd. II, S. 201.

30) Martin. *loc. cit.* (28). See also 'Reisen in den Molukken', Leiden, 1894, S. 369, footnote.

Belemnite, slopes gradually southwards. The neighbouring islets of Buano and Kelang are geologically identical with Buru, and non-volcanic. Mampa is entirely unknown.

Amboina and the Uliassers are volcanic, seemingly carrying some volcanic ruins, though none of them is sufficiently known. Nusalaut consists entirely of pyroxene-andesite, save a few patches of raised reefs on its shores. Biotite- and pyroxene-dacites as well as pyroxene-andesite build up the south coast of Saparu and Haruku, likewise the members of the Uliassers, but the raised coral reefs, here called 'karang', of Tertiary or Pleistocene age occupy the greater portion of the insular areas. The same geologic components prevail also in Amboina, except in the peninsula of Leitimor, where the Archaean complex of gneiss and mica-schists makes the foundation, penetrated by biotite-granite and peridotite. This is in turn overlaid by old sedimentaries of grey limestone, shale, and sandstone with interbedded sheets of diabase-porphyrite.

The mass of Wawani on Amboina proper is comparatively well known, through the works of v. Buch, Wallace, and many Dutch writers, as to its supposed geologic nature. Once it was considered to be a dreadful volcano; in later times it has been rejected from the list. K. Martin, in his recent work[31] which I am here following in its main points, endeavours to re-establish its *active* volcanic nature on the basis of an old document about the catastrophe of February, 1674. A subterranean commotion had been already inaugurated in 1671, and had attained its climax four years later, causing sea-waves, destructive earthquakes, and violent explosions of Monte Wawani. Despite his

31) 'Reisen in den Molukken', Geologischer Theil, 1ste Lieferung, 1898, p. 49.

ingenious interpretation of the account, the phenomena of earthquake and explosion are so hopelessly interwoven, that, from reading his paper, I am almost convinced that all were here dealing no more than a series of violent earthquake shocks. Our experience here in Japan shows that destructive earthquakes and explosions do not fall simultaneously. That Wawani is of volcanic origin and once a seat of activity can, however, be affirmed from the occurrence of pyroxene-dacite which moreover contains cordierite[32] as an accessory. It is very desirable to see the question of Wawani settled, for, upon it largely depends whether the chain of volcanoes of the Moluccas and of the Banda Sea have a claim to separate existence, or are only parts of one system.

From the foregoing, it is evident that the curved chain of islands from Kisser northwards, is only the shattered relic of an old mountain-range, composed mainly of crystalline schists and old massive rocks, beset with the Tertiary limestone and modern coral reefs, with the exception of a part of Moa, the island Tjoor, and possibly also Manawoka, which are said to be volcanic.

Wichmann pointed out the existence of a third, external zone, which may be indicated by a line, going through the Sula group, Great Obi, Misool, and then a part of New Guinea and the Aru group.

It has been repeatedly asserted[33] that there exists a close resemblance between the Banda islands and the Lesser Antilles.

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32) Vide Schroeder von der Kolk, *Neues Jahrb. für Mineralogie, etc.* 1896. I. Bd. S. 154. Japanese cordierite occurs in the volcanoes of Asama, Iwaté, and a hill near Nagano (Prov. Nagano), only in the form of *white* ejected blocks with conchoidal fracture, but, so far as I know, has never found in the main body of lava-flows.

33) Suess, 'Das Antlitz der Erde', Bd. I, p. 700. *Ditto*, Bd. I, p. 209.

Following an idea started by L. v. Buch, Prof. E. Suess recently made a critical study of the geology of the Lesser Antilles, which has resulted in the recognition of three zones, viz., (1) the first or inner zone within the concavity of the curved chain, which is exclusively of young volcanic origin ; (2) the next which comprehends the mountainous islands ; and (3) the third, exterior belt which comprises the Miocene and Quaternary formations.

We meet, according to Wichmann, the analogue of these zones in the Banda Sea with the innermost volcanic arc, constituted by a chain of islands from Roma to Banda, corresponding with that of the Lesser Antilles, caused by the falling in of the crust inside of the above arc. This great sink is itself the Banda Sea, and earthquakes frequent the peripheric zone, as in Amboina, Ceram, and other isles belonging to the series. The second and even the third zone can also be made out, of which enough has been already said in the foregoing pages.

We have a striking representative of geologic homology of the threefold concentric arcs in the Riu-kiu islands,[34] which stretch from the north of Taiwan (Formosa) to the south end of Kiu-shu, in which arcs the characteristic three zones can be more easily recognisable than those of the Banda and the Lesser Antilles.

It is to be expressly remarked that in the recent work of Verbeek,[35] the volcanic zone of the Banda group is made to go round in enclosed ellipse which passes through the South-west Islands, and then through Gunung Api, off Lucipara and the Tortoise isles, deviating from Wichmann's arc.

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34) Kotô, *Chishitsu-gaku-Zasshi* (The Japan Geological Magazine), Vol. IV.

35) Verbeek et Fennema, 'Description Géologique de Java et Madoura', 1896.

II. Inner Eastern Archipelago.

Within and to the immediate north of the great Malayan curve, there are three k-shaped islands, in a line from west to east under the equator, which have been regarded since the time of L. Horner[36] as a good example of geographic homologies, though it afterwards turned out that their resemblance is only superficial, for their inner, geologic structure by no means conforms with their outward likeness. These islands, Halmahera (Gilolo), Celebes, and Borneo represent old geologic blocks and other relics of South-eastern Asia, left as giants among the ruins of the long lost land, of which the former sea-board is clearly marked by the Great and Small Sunda groups, and the Banda Islands.

Their geologic relation with the circumscribing Malayan curve is not so clear, as might be looked for, though there exist at several points faint indications of their connection to which I may have occasion to refer in the sequel. But if we turn to the other sides, it soon becomes evident that their affinity with the Philippines is very close, being linked to them either by chains of volcanic islands or series of shattered cordilleras; and these geologic lines converge as we go northwards, presenting the same feature of 'virgation' as in Eastern Thibet.

Borneo.

Posewitz provides us with a concise description of the topography and geology of Borneo, so far as it was known at that

36) Wichmann, 'Die Binnenseen von Celebes', *Petermanns Mittheilungen*, 1893, p. 1. Peschel, 'Neue Probleme'. Wallace, Jour. Roy. Geogr. Soc., London. XXXIII. *Vide* also Wettstein, 'Die Strömung des Festen, Flüssigen and Gasförmigen', p. 49.

time, in his 'Borneo', and I cannot here do better than follow his work, supplementing it with a few notes I have gathered elsewhere.

Borneo is the largest of the Sunda Islands and rather broad. Our knowledge concerning its geography is very imperfect, especially of Beru and the 'central mountain'; the only exception being the coast region and in some degree the interior of the south, and the Chinese district of West Borneo. Mountains are crowded together in the north-west, and trend generally north-eastwards. At about the middle of the chain, one range bends north-west, terminating at Cape Datu, while the south-western branch stretches towards Cape Sambar. Near the junction of the two, the land rises to a considerable height, the so-called 'central mountains', and culminates at the granitic or dioritic G. Tedong. All the principal rivers of Borneo rise in this unexplored region, radiating towards the surrounding seas, each having an independent hydrographic basin of its own, which nearly corresponds to the political divisions, into which this large island is divided. From the central water-shed, the axial ridge proceeds north-eastwards to the peak of Kina-balu, 4175m. high, the loftiest of the whole island.

Crystalline schists, *alte schieferformation* (probably the Devonian), and the Carboniferous built up the above-mentioned chains, with the strike corresponding to the longest extension of the mountains, and pierced by igneous rocks of granitic and dioritic composition. Among (1), crystalline schists, mica-schist, hornblende-schist and the itacolumite-like quartz-schist are prevalent. By (2), the *alte schieferformation*, we understand that series of rocks, made up of the bluish phyllade and siliceous slate which is conjectured by many to be the Devonian, principally because of the occurrence of some imperfectly preserved

organic remains. The Carboniferous belt flanks the axial ridge on the side of Sarawak and Brunei, and appears again in a few patches on the north. Alternating layers of sandstones and semi-crystalline limestone veined with calcite constitute the main bulk of this belt, which harbours the flora of *Vertebraria*, *Phyllotheca*, and the bed in the Seba district (the Kinabatangan river) in British Borneo yields *Fenestella* and *Stenopora*, while that of the upper Kapua, Western Borneo, affords us *Marginifera*, all pointing to the rock-system being Devono-Carboniferous. (3) Clay-slate and siliceous slate are developed elsewhere and considered to have the Culm facies. These three complexes make up the elevated land, which Posewitz termed collectively the *highland formation.*

Quite recently, the first find was made known in the Sambas district in Western Borneo, of the Jurassic system of which the upper series[37] is characterised by containing the oval *Protocardia*, and *Exelissa*, and the Lias[38] by the occurrence of the genus *Harpoceras* of the group *H. radians.* In the Residency of Sarawak, Newton[39] announced the discovery of *Alectryonia amor*, D'Orb., which belongs to the Middle Oolite. This is all what we know about the Jurassic system of whole Borneo,* and this formation seems to be confined to the western region of the island.

37) Vogel, *Sammlungen. geol. R.-Mus.* Leiden, Bd. V, S. 128.

38) Krause, *ibid.*, Bd. V, S. 154.

39) The Geological Magazine, 1897, p. 407.

* As I have mentioned in the foregoing page 94, Wichmann and Rothpletz brought to light a few typical fossils of the marine Jurassic, belonging to the Malm and Lias in the island of Rotti. Since then, Martin and Vogel, Krause and Newton considerably enlarged our knowledge of the same system in Borneo. Lately, Sagawa found out a fossil, closely resembling *Alectryonia amor*, in Tosa in the island of Shikoku; and Inouyé gave also notice of the occurrence of *Harpoceras* of the species *radians*, Reineck, in the province of Nagato. It is the well-known fact that Neumayr in his celebrated essay on the geographic distribution of the Jurassic Formation, includes the entire region in his hypothetical Sino-Australian

Though the Cretaceous occurs over a limited space in the Seberuang, a tributary to the Kapuas river in West Borneo, it only became well known through preliminary notes by Geinitz.[40] Among the entombed remains identified, we find *Vola* cf. *quadricostata*, and *Trigonia* cf. *limbata*, indicative of the presence of the Upper Cretaceous. The typical Cenomanian fossil, *Orbitolina concava*, Lamark, is also found as in the Javanese Cretaceous,[41] and the *Gervillia horneenis*,[42] Mart. is said to occur in the Sambas district. Not less interesting is the occurrence[43] of *Sphærulites* and *Radiolites* in the south-eastern part (Martapura) of the island.

In contrast to the Cretaceous, the Tertiary terrene makes up the greatest part of the area, and the outline of the island is indeed determined by the extent of this formation. The highland formation, already referred to, occurs in narrow ridges and sporadic masses, serving as the back-bone and water-shed of great politico-hydrographic basins. These geologic islands project out between the rolling hills of the Tertiary strata, which elevate themselves as they approach the central, axial highland chain, lending special topographic relief to the aspect of the country. From its position the Tertiary is called collectively the upland formation. Shales, micaceous sandstone and limestone prevail throughout the area, and fall into the Older and Younger Series, of which the former may be divided again into

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continent; but these various discoveries unfortunately weaken the strength of his theory, and make me almost believe the "Central Mediterranean" of the Jurassic time to extend directly from the Atlantic to the Pacific Ocean.

40) *Zeitschr. d. d. geol. Gesell.* 1883, S. 204.

41) Martin, *Sammlungen, geol. R.-Mus.*, 1890, Bd. IV, S. 209–231.

42) *Ibid.*, Bd. IV, S. 198.

43) *Ibid.*, Bd. IV, S. 117.

three tolerably well-defined étages, viz., (α) the lowest, sandstone, (β) the middle, marl, and (γ) the uppermost, limestone. This complex seems to be developed to full advantage, and at the same time to be best known,[44] along the Riamkiwa river in Tanah-Laut, South Borneo. The first étage affords some technically important coal, and is characterised by the *Cyrena borneensis*. The marl étage is rich in fossils and full of *Orbitoides* and *Lithothamnium*. The uppermost bed, the horizon of the limestone contains *Orbitoides*, *Nummulites*, *corals*, and *echinoids*. Basalts and andesites pierce all the beds, but play only an insignificant rôle in rock-formation.

The Younger Tertiary is also coal-bearing, and has been separately grouped from the Old, not on palæontologic grounds but merely on stratigraphic grounds, and lately, Verbeek[45] has recast his former scheme, and now étage α is left to rest in the Eocene, β is assigned to the Oligocene (Nari group of India), and γ to the Younger Miocene; the Younger Tertiary will thus be Pliocene beds. Diluvial terraces and Alluvial swamps, holding diamond and gold, fill up the drainage basin of Barito, Kapua, Redjang, Mahakkan, Berau, and Bulongan, thus completing the geology of the island.

As I have said at the outset, the principal direction of the back-bone and also the prevaling strike of the old beds of the island is north-easterly. The same is true of the detached masses, wherever they occur, with variable dips to north-west and south-east. As the greater part still remains *terra incognita*, the time has not yet arrived to attempt to unveil the inner

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44) Verbeek und Böttiger, 'Die Eocänformation von Borneo.'

45) *Neues Jahrbuch für Mineralogie*, etc., 1882, I, p. 65.

geologic structure, and I am under the impression, after reading Posewitz's work, that even the axial chain does not fall into the category of the folded mountain-range.

Recently, quite a new aspect of the geologic structure of Borneo has been opened by Molengraaff,[46] who was one of members of the Dutch Borneo expedition in 1893-'94. One of the many discoveries he made is the existence of a chain of andesitic volcanoes, called by him the Müller Mountains, along the south side of the Kapuas river. Hitherto the rarity of neo-volcanic rocks has been considered to be characteristic of this large island; but as exploration has proceeded our former conception seems likely to turn out to be erroneous. On the north of the Kapuas, on the Sarawak frontier, there exists an east-west striking, folded mountain range, consisting of slate, hornstone, and sandstone (Palæozoic?). This Upper Kapua range seems to keep its direction far into the Mahakkan river district in East Borneo (Kútai); and the same holds true of the volcanic Müller chain and the Schwaner ridge. The latter trending north-eastwards forms the political and hydrographic boundary of the Kapua and Barito basins, and belongs to the category of tilted mountain-ranges with steep southerly cliffs, but sloping gradually to the north in the plateau like upland of the Melawi basin. Such is a brief account of Molengraaff's preliminary notice, differing greatly from former notions as to this district.

After all, we must confess that our data are too scarce to give insight into the geologic structure. The late Neumayr[47] rightly asserted that Borneo's position in the Eastern Archipelago

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46) *Petermanns Mittheilungen*, Bd. 41, 1895, p. 203.
47) 'Erdgeschicht', Bd. II, 1887, p. 657.

bears the same relation to that of Mexico amidst the Andese-Rocky system, it being a matter of great difficulty to decipher its connection with the neighbouring great mountain-systems.

Whether the axis of the Malay peninsula sweeps over to the Seratus ridge of Borneo, or the Banka-Billiton line goes over to Cape Sambar of West Borneo, nothing can be said with certainty, though a mere glance at the map would lead the observer to imagine the latter to be the case, though Verbeek[48] believes rather in the prolongation of the Banka tectonic line to the islet of Karimon Java. One point seems to be certain, that the highland formation with intrusive granites represents the tin-bearing Billiton and Banka with a laterite cover, exactly like the opposite West Borneo; and the same holds true for the granitic Karimata.

Cape Mangkalihat (Kamiongan) in the Strait of Makassar appears to have some genetic relation with the north arm of Celebes; and the orographic condition near Darvel Bay suggests that a ridge goes through the series of the Sulu Islands to the south-western tongue of Mindanao from the interior of North Borneo, but this remains as a fancy until the geology of the intervening islets becomes known. The massive of Kina-balu in North Borneo should form the continuation of the Zambales-Paragua chain in the Philippines.

New Island.[49]—A small island about 100 yards square, rose from the sea during the earthquake of November, 1897. It lies to the south of Banguey, North Borneo. The ground is clay? traversed by cracks from north-east to south-west, covered with

48) 'Description Géologique de Java et Madoura.'

49) The Geographical Journal, 1898, p. 298.

sandstone and coral fragments. From the fissure inflammable gases are exhaled. Its emergence was accompanied by two sea-waves, a rumbling noise, as well as a furious wind. This shows that the sea-bottom between North Borneo and Paragua is geologically not quite at rest.

Celebes.

Stratigraphically speaking,[50] granite, greenstones, gneiss, mica-schist and quartzite constitute the foundation of Celebes, overlaid by thick, red clay, and then by grey clay, marl, fine and coarse sandstones, which make alternating beds of marine, lacustrine, and terestrial origin, harbouring rich fossils. Upon the grey clay rests the thick Neocene limestone of coral formation, which in the interior rises up to an elevation of 1000 métres, while the same rock on the coast lies in direct contact with the living coral reefs. At some place, there are young lacustrine deposits in the form of a fresh-water quartzite, and bog iron ore, with animal and plant remains.

The main mountain-ridge runs in the meridional direction along the west coast with north-east deflection at the north end, the southern extremity being joined at one point to Lombok by a submarine plateau, and at another point to Floris, probably through the Saleiyer island. From the middle of the island one arm of land projects out to the south-east, and another to the north-east, thus giving a k-shaped outline to the whole Celebes. Both tongues of the land belong to young geologic formations.

The meridional ridge seems mainly to be built up of plutonic and Archaean rocks, which at the north end opposite Cape

50) P. Sarasin, *Verhadl. d. Gesell. f. Erdkunde. z. Berlin*, XXIII, 1896.

Kamiongan (Mangkalihat) in Borneo, turns at first north-east, and then due east, with the tectonic basin of the Gulf of Tomini in the inner (south) side of the mountain-curve. P. and F. Sarasin[51] crossed between Buol and Marisa in the western tract of the northern arm of Celebes, and found old eruptives and thick, red (Tertiary?) clay in the interior, with modern coral reefs on the shore, but not a trace of neo-volcanic effusives. The same explorers made another overland journey between Amurang and Gorontalo, across the northern peninsula, and made known the existence of a meridional tectonic line through Bolang and Malibaga. The westerly region lying between this line and the before-mentioned Buol-Marisa area is occupied by a granitic nucleus with a mantle of gneiss and shale, the latter being overlaid by Pliocene conglomerate,[52] which is made up of gravels of shale and basaltic materials. The coast is everywhere fringed with recent coral reefs. An equatorial trench-fault runs along the south coast and the Lake of Limbotto near Gorontalo is the deepest point of this bicataclase depression between the granitic 'horsts.'[53]

Along the before-mentioned tectonic line[54] through Bolang and Malibaga, the peninsular area, including Minahassa, Bolang and Mongondo has been depressed, and upon that sunken socle of conglomerate and *Orbitoides*-limestone[55] are heaped up several volcanic rocks, by which this portion of the island is characterised. The volcanic line traversing the portion in question represents only the prolongation of a great earth-fissure, which

51), 52) *Zeitschr. d. Gesell. f. Erdkunde z. Berlin*, Bd. 29, 1894.
53) Wichmann, *Petermanns Mitteilungen*, 1893, S. 9.
54) P. u. F. Sarasin, loc. cit. (46).
55) Martin. *Beiträge zur Geologie Ostasiens*, etc., Bd. III, p. 581.

as Centeno long ago pointed out, and is named the Sangi fissure by Wichmann,[56] may be traced from the volcano Sanguil in the southernmost point of Mindanao through Butulan (Sarangami), G. Awu in Sangi, G. Api in Siao, submarine solfatara near Banua Wuhu,[57] and Ruwang to the andesitic Klabat, Lokon, and the basaltic Sempu, in Minahassa in North Celebes. The chain with eleven volcanoes turns in a south-easterly direction, and proceeds through Bolang, Mongondo, and then Boliohutu, whence it leaves the land and enters Tomini Bay. The Tongean Islands and perhaps Tandjong Api,[58] near Poss, in Central Borneo belong to this long belt.

By the way, it may be noted that in the Sangi belt, the greatest among the volcanic islands is Sangi itself. It carries Gunung Awu, 1500 m. high. It made eruptions in 1641, 1711, 1812, 1856, and so lately as 1892. Its activity is of the Asiatic type. In the last eruption it ejected a large quantity of ashes and sent down voluminous mud-streams. It was accompanied by a shake over an extensive area, earthquakes being felt in Makassar at a distance of 1,200 km. from Sangi, and even on the coast of Floris, where they were followed by sea-waves.[59]

As I have said, the meridional ridge of Celebes runs along the whole west coast, the axis of these mountains being built up of crystalline schist, tourmaline-quartzite, and glaucophane-schist[60] penetrated and overflowed by andesite and basalt. The whole complex is flanked with tuffs which make a fertile plain along the Strait of Makassar. This in turn is overlaid by the

56) *Zeitschr. d. deutsch. geol. Gesell., Jahrg.* 1893, p. 546.
57) Wichmann, *Natuurkundig Tijdschrift voor Ned. Indië*, Dl. LVII, 1897, p. 220.
58) P. u. F. Sarasin, *Zeitschr. d. Gesell. f. Erdkunde. z. Berlin*, Bd. 30, 1895, S. 350.
59) Wichmann, *Zeitschr. d. deutsch. Geol. Gesell.*, 1893, S. 545.
60) Wichmann, *Neues Jahrbuch f. Mineralogie*, etc., 1893, Bd. II, S. 176.

Neocene *Orbitoides*-bearing limestone, forming an inland cliff. Wichmann[61] found leucite rocks in the tuffs, which may justify us in saying that these rocks occur largely among the volcanics of this region. The east chain of South Celebes runs parallel to the west coast of the Gulf of Boni, and, with the already-mentioned west range encloses the long central basin of Walanné with inundation lakes of Tempé and Sidenreng.

The geological history of South Celebes, deduced from the foregoing, may, following Wichmann, be summarised in the following few words. The island of crystalline schist on the west coast had become faulted, and through the meridian fissure the neo-volcanic rocks had intruded and overflowed, and then formed detached islands fringed with the Neocene coral reef, which has become now a compact limestone. At the same time, materials of schists and volcanics, in consequence of transgression, had formed the sandstone, holding *Callianassa Dijki* Mart., on the Boni coast. At the end of the Neocene time, a considerable negative movement had caused detached islands to unite into a peninsula; the encircling coral reefs and the thick sandstone-deposits had also risen from the sea. During the early Pleistocene time, further changes in the configuration of South Celebes took place. The south was the scene of great eruptions and by the accumulation of the matter ejected Lompo-Battang, as well as Bulu Bonte Uhu were built up. Contemporaneous with these subterranean convulsions, the sandstones of the Boni coast were folded and upraised, thereby producing the tectonic valley of Walanne in the interior. This great longitudinally folded basin

61) 'Leucitgesteine von der Insel Celebes', *Natuurkundig Tijdschrift voor Nederlandsch-Indië*, Deel LIII, Aflevering 3, p. 315.

had been once occupied by the sea, on the bottom of which the Pleistocene sediment had deposited, harbouring a rich fauna, scarcely differing from the now living fauna of the neighbouring seas.[62]

A brief note on Saleiyar may here be conveniently inserted in connection with Celebes. It is a prolongation in a straight line of the east coast of the south-west peninsula of Celebes, but disjoined from it by the Strait of Saleiyar. The island stretches in a meridional direction and is of narrow east-west breadth. The mountainous, eastern half consists entirely of andesites and trachyte, which had welled out from the meridional fissure, formed at the time when the Gulf of Bóni was formed by depression; while the west is rather flat, being built up of tuffs, sandstones, and marls with *Pulvinulina*, *Orbulina* and *Globigerina*, overlaid by the Neocene coral limestone. Igneous rocks form the foundation of the whole island.[63]

Gilolo.

The likeness in general form of Gilolo or Almahera to Celebes is much closer than to the largest of its sister islands, Borneo, owing to the parallelism of its dislocation-lines—one equatorial, the other meridional—with those of Celebes, tectonic lines which seem to govern also the forms of a few of the neighbouring islands. Gilolo, thickly covered with forests, is a geologically neglected island, and there is too little known about it to give sufficient insight into its tectonic structure. Judging,

62) Schepman in Wichmann's paper, 'Die Binnenseen von Celebes', *Petermanns Mittheilungen*, 1893, p. 18.

63) Wichmann, 'Zur Geologie der Insel Saleijar', *Natuurkundig Tijdschrift voor Ned. Indië*, Dl. LIV, p. 1.

however, from the map subjoined to Schneider's paper,[64] granite and metamorphic schists, together with a complex of limestone, appear to build up Gilolo, Batian, the non-volcanic Great Obi (Ombira), and the Sula islands, all included in the Moluccas or Spice Islands. According to the recent observations of Kükenthal and Retzgers,[65] Gilolo's geologic elements are crystalline schists, peridotite, andesite, and other neo-volcanics, besides coral-limestones. Batian is in part andesitic, with some traces of hot springs, and a doubtful volcanic cone.

Along the west coast of Gilolo,[66] a volcanic chain starts from Makian,[67] and proceeds, quite independent of the Banda volcanoes, through Tidore, Mitara, Ternate, and Hiri, whence it enters the north arm of Gilolo which carries the Gunungs Tala, Duon, Todekku, Onu, Gamma-Kunorra, Tubaru, and then passes into the Tolo group near Galela Bay, here embracing Tarakan, Manuya, Tobelo, and Duko, the last of which made an eruption in 1550, accompanied by earthquakes.[68] The andesitic Tidore is an extinct-volcanic island, with hot springs near the shore. Makian made eruptions in April, 1760, 1819, 1846, and in December,

64) *Jahrb. d. k. k. geol. Reichsanstalt*, 1876, p. 113 et seq.

65) Works of both authors are cited in K. Martin's 'Reisen in den Molukken', Geologischer Theil, 1ste Lieferung, 1897.

66) Wichmann, 'Die Binnenseen von Celebes', *Petermann's Mittheilungen*, 1893, p. 3.

67) K. Martin, in the work cited above, seems to be at variance with Wichmann as to the starting point of the Moluccan volcanic chain. Martin is disposed to think the chain passes southwards through Batian and Manipa Strait to Wawani in Amboina. As the test point of its substantial continuity, which seems to him to withstand any serious objections that might be raised against it, he produces the fact of the synchronous occurrence of subterranean convulsions; for, these events happened almost simultaneously:

20th, May, 1673.	Explosion of the Gamma Kunorra in Gilolo.
12th, July. 1673.	Earthquake in Amboina.
12th, August, 1673.	Explosion of Gamma Lamma in Ternate.
17th, February, 1674.	Explosion of Wawani in Amboina.

68) Wichmann, 'Der Ausbruch des Vulkans Tolo in Halmahera', *Zeitschr. d. Deutsch. geol. Gesell.* 1897, p. 159.

1861. The active Gamma-Kunorra exploded in 1673, spreading ashes even to the distant Sangir group; and Ternate, which had shown activity in 1840, experienced a violent explosion also in August, 1673. Makian, Ternate, and the Gamma* (Kunorra are the trillings of the Moluccan volcanoes. K. Martin[69] quotes in his recent work, Valentijn's words: 'Man meint auch, dass dieser Berg (in Makian) nebst demjenigen von Ternate und dem Gammacanorre....., nur ein und dasselbe Grundfeuer haben, welches aus drei verschiedenen Oefen ausbricht und ausdampft. Bald glüht der Eine etwas stärker, bald wieder der andre.' The chain of volcanoes of the Molucca fissure, which we have so far traced, seems to touch Kaboroan of the Talaur group, whence it proceeds to Namusa, in which is situated the extinct volcano Mengampit. The prolongation of this line goes through Cape S. Augustin to the volcano Apo in Mindanao, where the volcanic chain of the Sangir fissure from North Celebes unites with this tectonic line.

The Philippine Islands.

Within the great Malayan arc, we have seen, there are three large, homologous islands, Borneo, Celebes, and Gilolo, besides a number of dependent isles, forming an island-world in South-east Asia, attaining almost continental dimension. If, therefore, the claim of Australia to be the fifth division of the globe is admitted, Wallace,[70] would ask for this great archipelago that it be called the sixth.

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* The Burmese word *yoma* and the Moluccan *gamma* seem to me to be in close phonetic relation with our *yama*, meaning a mountain.

69) 'Reisen in den Molukken', Geologischer Theil, 1ste Lieferung, 1897.

70) Journal of the Royal Geographical Society of London, Vol. XXXIII, p. 219.

From the inner group of the archipelago, that is to say, Borneo, Celebes, and Gilolo, radial ridges of cordilleras and chains of volcanoes converge, like the frame of a fan, towards the Philippines, which therefore, present a variety of orographic features. Geologically they have been reconnoitered by v. Drasche,[71] and some others, while Prof. Suess has ably sketched the geology of the whole Philippines from his wide knowledge of the literature of these obscure Spanish islands. From a study of them we learn that they have parallel ridges separated by tectonic valleys, one of which extends from the Bay of Butuan to that of Davao in Mindanao, while another goes from the Bay of Lingayen to Manila, disconnecting the main chain of Luzon from the westerly Zambales.

The Sierra de Zambales is a meridional ridge, made up of an old stock of gabbro, serpentine, and diabase-like rock, besides a red, hard siliceous slate (? Radiolarian chert), and at some place a limestone of unknown age. On the east side of the sierra, the whole seems to be overlaid by an enormous thickness of trachytic tuffite, from which the feldspar sands are derived. The latter cover the flat and form the ground of Pampanga, north of Manila. Along the west coast near Masinloc, a thinly bedded marly tuffite makes its appearance, and attains a considerable thickness. This was made the subject of study by Karrer, which resulted in the recognition of many species of Foraminifers, identical with those of Kar Nikobar, usually referred to the earlier Miocene.[72] The volcanic, southern Zambales trends a little to the south-east, but its main ridge runs close by the

71) 'Fragmente zu einer Geologie der Insel Luzon', 1878, Wien.
72) R. v. Drasche, 'Fragmente.' etc.

west shore, passes through the islands of Lubang, and the basaltic Calamians, and finally reaches Paragua, which seems to be connected with the north end of Borneo. In Paragua, an old limestone is said to occur. The Zambales-Paragua ridge curves quite like the coast of Annam, just as New Caledonia and New Zealand conform to the outcurve of Eastern Australasia.

The ridge of Northern Luzon forks into two arms, viz., the Cordillera del Norte and the Sierra Madres, with the basin of the Rio Grande de Cagayan between them. In the tobacco-producing region, Isabella and Nueva Vizcaya, of that basin, especially in the former, the earlier Miocene tuffite, and compact sandstone seem to have a wide distribution, as is proved by the occurrence of the typical fossils, viz., *Vicarya callosa* Jenk., *Ranella ranionoides*, Mart., *Rostellaria javana*, Mart., just as in Cebú and Java.[73]

Separated on the east from the Cordillera del Norte by the Rio de Abra, and the Rio Agno, and on the west, from the Sierra de Zambales by the Golfo de Lingayan there runs the meridional Sierra Tovalina through the maritime provinces of Union, Ilocos Sur, and Ilocos Norte. Chlorite-schist and sericite-schist seem to form the foundation of this ridge, as can be seen in a transverse valley near the port of Vigan. This geological island of crystalline schists, which seem to have some resemblance to the oldest rocks of Taiwan (Formosa), is concealed by its covering of the Agno bed, a complex of sandstone, and breccia derived from the detritus of diabase, gabbro and diorite, which have intruded through and overflowed the Archæicum. At a later time, volcanic activity was renewed through eruptions of trachyte,

73) K. Martin, *Sammlungen des geologischen Reichs-Museums in Leiden*, Bd. V, Heft 3, p. 58.

rhyolite, and hornblende-andesite,* whose derivatives—tuffite and marl, and the contemporaneous deposit of coral limestone cover the greater part of the area. As the submersion still continued, coral reefs and the breccia of coral limestone were formed, being associated with the detritus of young volcanic rocks. The corals which afford the substratum of the reef are *Galaxæa*, *Favia*, *Mæandrina*, *Porites* and *?Astræopora*, which scarcely differ from the living ones, and have even left behind an atoll at La Trinidad at an elevation of 4,000 feet. Volcanoes seem not quite at rest, for Monte Sto. Tomas, 3,120 Spanish feet high, was said to have made an eruption or explosion in 1635 or 1641.

The inland chain of the west coast, the Cordillera del Norte, seems mainly to be made up of tuffite and coral reefs, with the extinct volcano of Monte Date in Lepanto; its southern prolongation, the Cordillera Central is of hornblende-andesite.

This main western chain meets at the gabbro massive of Caraballo Sur with the Sierra Madres, which runs up the unexplored east coast of North Luzon.

It is a great pity that our knowledge of the geology of North Luzon is so meagre and defective, that we can draw no inference from it about the geology of Taiwan.

From the Caraballo Sur massive which serves for the watershed of all the great rivers of Luzon, the axial mountain ridge

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* Oebbecke has made a microscopic analysis of rocks collected by Semper, and he mentiones the occurrence of hornblende-andesite of a pumiceous structure in the military districts of Lepanto and Bentok in Northern Luzon, and on the volcanoes of Iriga, Bulusan, Labo, Isarog in Camarines, and in the island of Leyte. All the rest of the volcanic districts are mainly made up of the olivine-bearing augite-andesite of a hyaline type. Feldspar-basalt comes from Mindanao besides andesites. *Neues Jahrb. f. Mineralogie*, etc. Beilage-Band I, S. 452 *et seq.*

runs close by the east shore of the Lake of Bay, and trends south-eastwards. The core of the sierra seems to be of crystalline schists, which occupy a considerable area to the north-east of Manila, overlaid in part by the Eocene Nummulitic limestone, first noticed by v. Richthofen[74] at Binangonan, on the northern shore of the Laguna de Bay. On the south, the mountain resolves itself into at least three parallel chains, as may be conjectured from the outlines of the peninsulas and islands, as well as from the direction of the chief elevations. The westernmost ridge consists of Tabayas, Burias and Ticao; the peninsula of Camarines constitutes the middle; while Caramuan, Batan, and Samar make up the third ridge. The groundwork of the Tabayas peninsula is crystalline schists, overlaid on the north by the tuffite of Majayjay, and on the south by the later Miocene or Pliocene coral limestone.

As regards the geology, the peninsula of Camarines is similar to that of the preceding. Protogene-gneiss and talc-schist are extensively developed in the Malaguit region, with auriferous veins, while the Pliocene limestone makes up the entire west coast. Workable seams of brown coal occur associated with the above limestone. Moreover, Camarines abounds in volcanoes, of which we may mention Tetas, Colasi, Isarog, Iriya which made an eruption in 1628 or 1648, and lastly Albay, all arranged in one series corresponding to the form of the peninsula, and constituting the Albay or Mayon system of volcanoes. Albay is the type of volcanoes of the Philippines; it presents a beautiful cone, and is in a state of constant activity. It has made fourteen eruptions since 1716, and on the 26th, July,

74) *Zeitschr. d. deutsch. geol. Gesell.*, 1862, p. 358.

1897, it was again active, pouring forth streams of lava and ejecting ashes in large quantities. Liboy and two other localities were destroyed with many of their inhabitants. According to Roth, Caramuan seems to consist also of crystalline schists, and lignite beds; and this peninsula, together with the islands of Batan and Saramar, makes the third, easternmost ridge.

The form of Masbate is geniculate. Its peculiar outline has already attracted the attention of v. Drache. One arm conforms itself to the prevalent, south easterly direction, the other wing assumes a south-westerly trend, oriented exactly like Paragua. Thus the mountain-system diverges just as in the Eastern Alps. Its geology is, however, unknown.

In Cebu, diorite and its tuffs make the foundation, covered with the Nummulitic and the post-Pliocene limestone, with the Miocene marl intercalated between the limestone-complex. The whole has been folded into parallel ridges, corresponding to the direction of the west arm of Masbate.

The Miocene lignite bed* recurs here as in Camarines. The same seam appears in the Isla de Negro, and in West Mindanao near the Bay of Sibuguey. It seems probable, as Suess has rightly remarked, that Cebu, Negro, and West Mindanao constitute an independent system, which starts from Masbate and reaches Borneo through the Sulu group. Sulu or Joló, the largest of the group is basaltic, and fringed with coral reefs. The same is the case of Ilo-ilo, lying further north.

Leyte may be considered as the prolongation of the east arm of Masbate. It is geologically unknown, though it is said

* The marl at the coal mine of Alpaco, 298 m. high, contains *Vicarya callosa*, Jenk., which characterises the later Miocene of the East Indian Archipelago. K. Martin, *Sammlungen des geologischen Reichs-Museusum in Leiden*, Bd. V, Heft 3, p. 60. The same fossil recurs in Tsuki-yoshi, Mino province, in Central Japan.

that here occurs hornblende-andesite. The eastern sierra of Mindanao lies in the direction of it. The ridge is composed of an old slate, dioritic conglomerate (like the Agno bed), limestone, and serpentine. Separated from the sierra by the Butuan-Davao basin, there runs a western ridge, nearly parallel to the former. It is a gold-producing chain, being built up of quartzite and clayslate. The eastern sierra ends with Cape S. Augustin, opposite to Gilolo, and the western mountain terminates in Cape Tinaca, pointing southwards to Minahassa in North Borneo.

It now remains for me to consider the volcanic chains. As I have already said, the Molucca chain, starting from Makian, goes through Ternate and the north of Gilolo, then through Tulur or Talaut, and Namusa, and finally reaches the solfataric volcano, Apo, in Mindanao, passing by the way a volcano near Cape S. Augustin. The Sangir chain, on the other hand, comes from the north arm of Borneo and passes through Ruang, Siao, Sangir, Butulan (Sarangani), and the volcano Sanguil near Cape Tinaca, and finally unites with the Molucca system at Apo, 9,000 ft. high, the loftiest cone of the Philippines. The united chain reaches the volcano of Camiguin in Butuan Bay, an island formed in 1871, accompanied by a great eruption. It further touches the trachytic island of Biliran, lying to the north of Leyte, and then continues to the Albay chain of Camarines, already referred to. The crater of Cagua, near Cape Lugano in North Luzon, may be looked upon as its prolongation and the same chain goes through the Babuyans, Batans, and the Bashi Islands. It leaves then the Philippines, and enters the island of Kôtô-sho (Botel-tobago) of the new Japanese domain. The island of Claro of the Babuyan group is said to be a lofty active volcano, which serves the purpose of gigantic natural light-house.

In conclusion, I must not forget to mention the very important volcanic group of Laguna. Lying between the Zambales-Paragua cordillera on the west and the main sierra on the east, that portion of South Luzon, lying to the south of Manila, was submerged during post-Eocene time, and then effusive rocks got piled up at different periods, creating the andesitic Majayjay and the basaltic Taal. On this account, a portion of the sea became barred in, forming the Lake of Bay, and the Bay of Manila on the north. The water of Bombon should be considered as a crater-lake, in the middle of which appears the central cone of Taal, which is constantly emitting steam and vapours. Besides these two volcanoes, there are Magniling and Sosoncambing, each having its own crater. The andesitic Arayat, north of Manila, is an extinct crater, and the cone of Halcon in Mindoro, is the second in height of all the volcanoes of the Philippine Islands.

Contents.

PLATE I.

This Plate is based on the map, Bijlage, I., 'Kaart van den Oost-Indischen Archipel,' subjoined to the recent work of Verbeek et Fennema, *Description géologique de Java et Madoura*. I consulted also Berghaus's *Physikalischen Atlas, Gewässerkunde*, No. X. Tectonic lines and the zones of volcanoes of the Sangirs, the Moluccas, and the Philippines in the map are my own.

KOTÔ MALAY ARCHIPELAGO

Tectonic Map of the Malay Archipelago

Based on Verbeek's Map

Scale 1:12,500,00

1000 Fathom line — 2000 Fathom line

Tectonic line — Volcanic front

Limit of Tertiary rocks

CHINA

BURMA

TONGKI

SIAM

CAMBODIA

PEGU SEA

MALACCA

SUMATRA

BORNEO

JAVA SEA

CELEBES SEA

CELEBES

MOLUCCA SEA

MOLUCCA

PHILIPPINE

OCEAN

NEW GUINEA

BANDA SEA

TIMOR SEA

AUSTRALIA

INDIAN OCEAN

Equator

95° 100° 105° Greenwich 110° 115° 120° 125° 130° 135°

lithographed by the Tokyo Tsukiji Type Foundry

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Vol. XI, Pt. 2, published March 14th, 1899.

Price in Tōkyō, ... yen 0.38.

明治三十二年三月十日印刷
明治三十二年三月十四日發行

編纂兼發行者　東京帝國大學

印刷者　東京市京橋區築地三丁目十五番地　野村宗十郎

印刷所　東京市京橋區築地二丁目十七番地　株式會社　東京築地活版製造所

賣捌所　東京市日本橋區通三丁目十四番地　丸善株式會社書店